IV

CASE STUDIES

FINDINGS OF THE ROWLETT CREEK BASIN EXPANDED FLOODPLAIN INFORMATION STUDY

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INTRODUCTION

The overall objectives of the Rowlett Creek Expanded Flood Plain Information (XFPI) Study were to develop basic floodplain information (flood flows, flood depths, and floodplain delineation), the general flood damage potential (average annual and single event flood damages), and the implications of land-use change on the environment. We considered land usage in 1976 as a base, use in 1964 as the historical past condition, and three possibilities for land-use as the future conditions. Recently developed spatial data-management and analytical techniques were used in this study. We subdivided the entire watershed into rectangular grid cells of 1.1478 acres (200 ′ × 250 ′) and assigned specific numerical values to the cells to represent land use, environmental habitat, topographic elevation, soil type, spatial location, etc. These small cells, the basic units for analysis purposes, are then stored in a massive computer data bank. There are approximately 77,000 unique cells in the Ro vlett Creek data bank, each with its own set of characteristics. They can be treated individually or as a group for informational purposes, for analysis of storm runoff (imperviousness characteristics), for flood damage calculations (if located within the floodplain), or for environmental change assessments (as land use changes).

The Rowlett Creek watershed, as shown in figure 1, is located northeast of the city of Dallas, Texas, and is in Dallas and Collin Counties. Rowlett Creek drains into Lake Ray Hubbard and is part of the upper Trinity River Basin. The study area is a relatively small watershed, draining an area of about 137 square miles. Streams within the watershed include the

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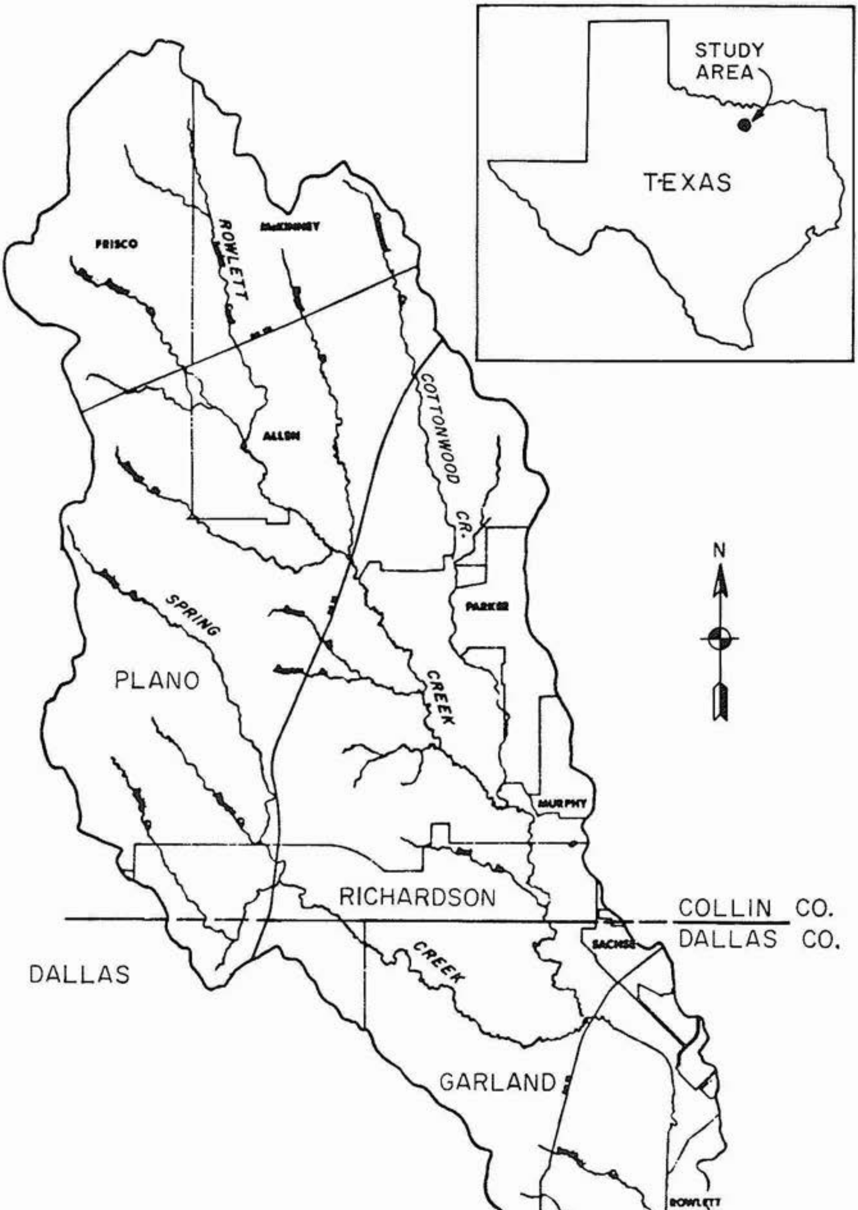

FIG. 1. ROWLETT CREEK WATERSHED MAP

main stem of Rowlett Creek, two major tributaries (Cottonwood Creek and Spring Creek), and numerous smaller tributaries to these streams. The dynamic growth of the communities with corporate limits within the watershed is radically changing the basin from primarily rural to highly urbanized. The cities of Plano and Allen are two of the fastest growing communities in Texas (Plano grew from 3,695 in 1960 to an estimated 53,000 in 1977). Urban development is generally moving into the upper watershed, a fact which makes it ideal for evaluating effects of upstream land-use change.

ANALYSIS METHODOLOGY

The procedure used for the Rowlett Creek XFPI study is summarized in figure 2.

Data management

Data management as defined for this paper begins with the collection of raw data and extends through the development of a computerized data bank capable of rapid and efficient access for subsequent analysis in each of several functional areas. We decided to select a procedural concept that would allow aggregation of one or more of the variables within the overall data set from some small, spatially oriented unit to one of several other larger spatial units. Use of this data management approach is neither new nor unique: it has been used by landscape architects and planners for many years. Using it to perform specific engineering and related water resources analyses has gained favor, however, as a result of the development efforts of the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers, as well as those of other agencies, institutions, and private firms.

Data collection

Four classifications of data were considered when establishing the study objectives:

DATA MANAGEMENT	ANALYSIS	RESULTS
Data Collection	Hydrology	Flood Hazard Information
Data Encoding	Hydraulics	Flood Damage Information
Data Processing	Economics	Environmental Information
Data Bank Creation	Environment	Resource Management Information
Access to Data Bank	Resource Management	

FIG. 2. STUDY PROCEDURE

1. Areal data (such as hydrologic boundaries, land use, and soils)
2. Contour proximal data (such as topography)
3. Line data (such as transportation routes)
4. Point data (such as archeological sites).

The base map selected for the study was the set of U.S. Geological Survey 7½-minute quadrangle maps at a scale of 1:24,000. We also used Soil Conservation Service soils maps for Dallas and Collin Counties.

During the data collection phase, any new mapping required conformed to the base map system. For example, new aerial photographic coverage at the base map scale of 1″ = 2000′ was purchased specifically for this study. The Department of Forest Science at Texas A&M University then delineated 22 existing land-use categories and scaled the final maps to the base map system.

Data encoding

Encoding is the conversion of spatially related data into digital form for subsequent processing into a grid cell data bank. Two procedural methods were used on the Rowlett Creek study.

Grid cell encoding (placing a transparency of the grid cell system over the mapped variable of interest) is a relatively simple but time-consuming method. Each grid cell is assigned, by visual inspection, a value corresponding to individual categories of the particular variable being encoded.

The second type of encoding is usually referred to as digitization, and can be accomplished manually or automatically (e.g., with a line-follower digitizer). With this method, one transfers the mapped data to a sufficient number of X-Y coordinates to define the spatial extent of the data variable being encoded, whether those data are areal, line, point, or contour-proximal. The original data maintain their identity, but further processing is required to convert the digitized data to grid cell data.

Initially, we decided on automated digitization to encode existing-condition data variables. Numerous software problems forced a departure from this approach to the grid cell encoding procedure for the more complex variables (such as land use and soils). We continued to use the automated version for the less complex variables, including sub-basin boundaries and damage reach boundaries.

Data processing

After the basic data had been encoded, they were manipulated to produce a grid cell data file for insertion into the data bank. For the cell-encoded data, a computerized graphic output (map) of the particular variable under consideration was produced and visually edited by overlaying a transparent original source map. For data variables digitized automatically, errors on a computer-plotted map were corrected on a cathode ray tube terminal. Spatial coordination of the edited, digitized data to the base map system was then accomplished by the computer program REGISTER developed by HEC. After registration, grid cell files were generated from the digitized data using the computer program AUTOMAP II developed by Environmental Systems Research Institute of Redlands, California.

Data bank creation

After the basic data had been cell-encoded, edited, and corrected, or digitized, edited, corrected, registered, and converted to grid cell representations by AUTOMAP II, they were inserted into the data bank. The computer program BANK developed by HEC was used to produce a systematic stacking of individual grid cell representations onto magnetic tape. This grid cell storage concept produces an easy to use, sequential cell-by-cell arrangement.

Access to the data bank

The Rowlett Creek XFPI study makes use of "traditional" methods where possible and automated analysis and displays where appropriate. The "traditional" methods include use of unit hydrograph computations for flood discharge determinations, step backwater analysis for water surface profiles, and flood damage economic computations from elevation-damage-frequency-discharge integrations. Our study departed from previous approaches both in the basic data gathering and management and in the use of computer programs to analyze those data. After a data bank of all needed variables had been created, utility computer programs manipulated the data into specific analytical forms that were subsequently prepared for use by analysis computer programs such as HEC-1. The utility and analysis programs perform the necessary computations and return the results of the data files either for display on a cell-by-cell basis or for further analysis.

ANALYSIS PROCEDURES

Hydrological analysis

The hydrological analysis used in the study was centered around a modified version of the HEC-1 Flood Hydrograph Package computer program. The HEC-1 program was altered to use Dallas-Fort Worth urbanization curves and Fort Worth District Corps unit hydrograph procedures. A utility program, HYDPAR, was used to retrieve imperviousness information from the grid cell land-use data file and to compute sub-basin or watershed characteristics, which were then used as input into the HEC-1 unit hydrograph procedures.

The HYDPAR program computes sub-basin or watershed characteristics by selectively processing data variables from the grid cell data bank.

The principal hydrologic parameters that are calculated are drainage area, areal breakdown of land use within the sub-basin, sub-basin imperviousness, and Snyder's lag (t_p) based on the imperviousness.

The Rowlett Creek watershed was subdivided into 101 sub-basin areas for unit hydrograph and flood hydrograph development at each discharge location. Flood hydrographs were routed from one discharge location to the next by the modified "PULS" Routing Method. The only U.S. Geological Survey stream gauging station in the basin, located on the main stem of Rowlett Creek, provided only eight years of continuous record. Even with this short record, a historical discharge-frequency curve was developed to be used to calibrate the hydrologic model being used in the study. Synthetic unit hydrographs were developed for each of the 101 sub-areas, and two major floods (May 1969 and December 1971) at the Rowlett Creek gauge were reproduced by the computer.

Figure 3 depicts the overall hydrologic analysis procedures from basic model development and calibration to computation of discharge frequency data for various watershed conditions.

Hydraulic analysis

The HEC-2 water surface profile backwater program was used in hydraulic analysis to define the flood elevations and floodplain limits of the various streams. Water surface profiles for the 10-, 50-, 100-, and 500-year frequency floods, as well as for arbitrary discharges, were computed on all study streams. The hydraulic model for each stream was based on existing channel and overbank conditions, taking into account all existing bridges and those under construction. The "existing condition" (1976) flood profiles and floodplains have also been incorporated into flood insurance studies for the appropriate communities.

The 100-year frequency flood profile for each stream became the reference flood profile for flood damage calculations. Damage reaches, which were selected along the streams on the basis of uniform profile shape, had index stations where accumulated flood damages were calculated. The flood profiles were used to develop rating curves (discharge vs. elevation) at these index stations for use in the economic analysis calculations. Basic computations (for flood insurance purposes) of changes caused by encroachment of buildings on the floodway were also included in the hydraulic analyses for the XFPI study.

Economic analysis of flood damages

Analysis of general flood damage potential included delineation of land use in flood-prone areas, computation of damage from a single flood, and computation of expected (average) annual damages. The Hydrologic Engineering Center has developed an automated method of generating

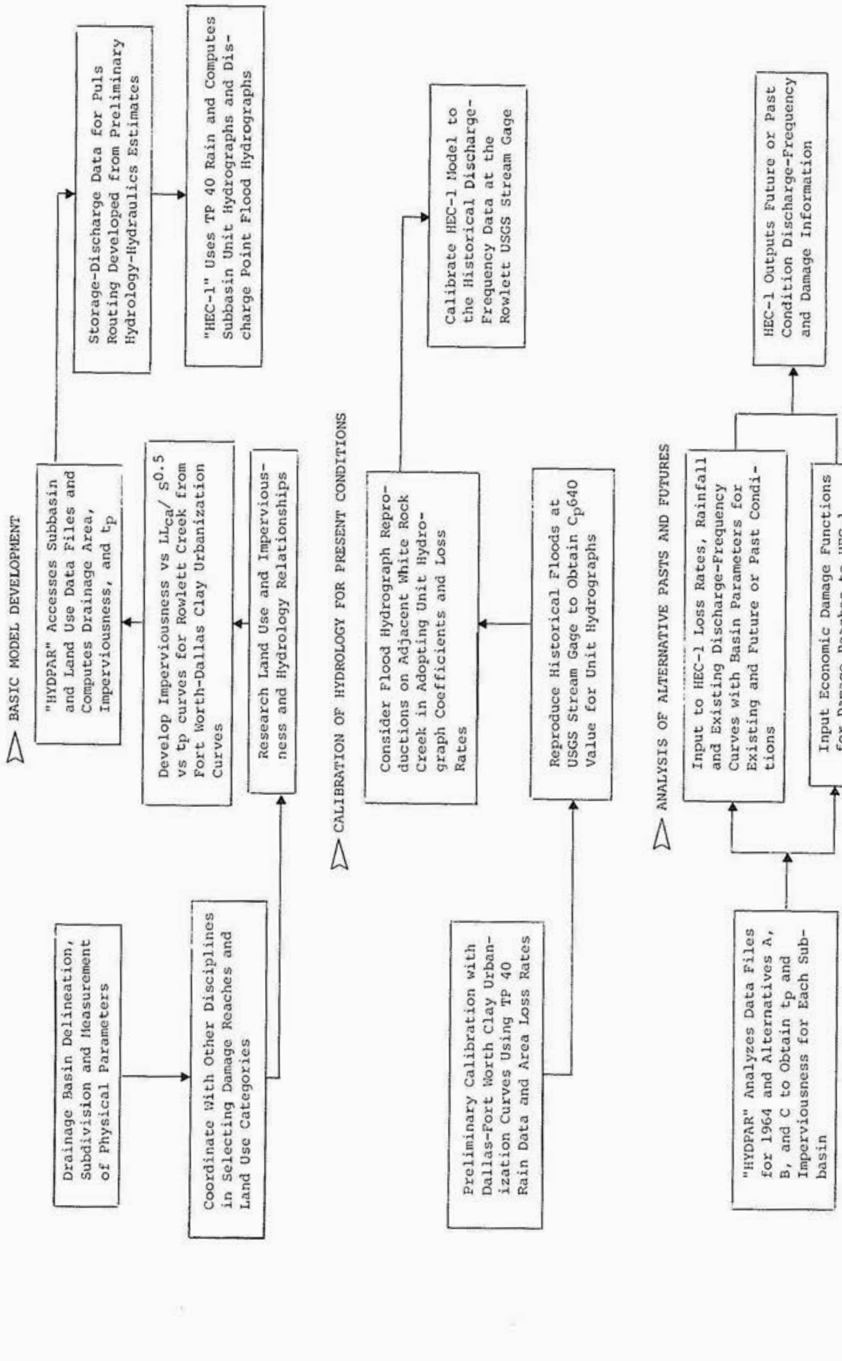

FIG. 3. HYDROLOGIC ANALYSIS PROCEDURES

damage potential functional relationships from the grid cell data bank. The method uses a program called DAMCAL to compute a unique elevation/damage relation for each grid cell within the floodplain (based on ground elevation, land use, and potential for damage) and to group the individual cell functions at an index location for each designated damage reach. The damage functions are then merged with flood-frequency data and hydraulic stage data within the HEC-1 program so that average annual damages for each damage index location, land-use category (commercial, multifamily residential, etc.), and evaluation condition (present or future) can be computed.

The DAMCAL program searches the master data bank for specific variables to be used in the economic analysis. It must determine from the data bank such information as: 1) which individual cells are within a damage reach; 2) the land-use classifications of those cells; 3) the topographic elevations assigned to the cells; and 4) the reference flood elevation at or nearest to each of the cells. Combining this information with direct input data such as the composite damage functions (a stage-damage per unit area function for each land-use category) and the reference flood elevations at the index locations, the program aggregates and then tabulates the elevation/damage for all pertinent land-use categories and damage reaches.

A recently developed HEC program, ATODTA, allows direct use of the information generated by DAMCAL, basic hydrologic and economic data derived from other sources, and the HEC-1 computer program, which provides the final economic analysis. ATODTA reads discharge-frequency and discharge-elevation data cards and elevation/damage data generated by DAMCAL; it also performs consistency checks, aggregates damage categories, and writes input data onto magnetic tapes for direct use by HEC-1.

Environmental analysis

The environmental analyses for the Rowlett Creek XFPI Study included a general environmental inventory, a simplified assessment of nonpoint source water pollution, and general resource management planning assessments.

The environmental inventory, which related biota to each of nine land cover/habitat categories as of 1976, established a base from which ecological changes, resulting from land-use changes, could be subjectively evaluated. After the pertinent land cover/habitat categories were defined and mapped, and the various animals and plants associated with those habitats were catalogued, computer programs determined habitat acreage losses and gains under future land-use conditions. The net acreage changes for habitat categories were calculated by the coincident tabulation option of the program Resource Information and Analysis (RIA) developed by HEC.

Then the resultant changes in acreage for each habitat were reviewed and written evaluations prepared.

Calculations of annual nonpoint source water pollutant loads were considered sufficient to note connections between these loads, the areal extent of land-use change, and the time over which those changes occur. Four basin-wide land-use conditions (the 1976 base condition and the three future conditions) were examined. For each of these four land-use conditions, average annual pollutant loads for four constituents (5-day Biochemical Oxygen Demand, total nitrogen, total phosphorous, and sediment) were calculated. Two components of each average annual load were calculated: the rural land-use contribution by using pounds-per-acre-per-year loading factors, and the urban contribution by determining the average annual runoff volume and multiplying by concentration factors expressed in milligrams per liter. Calculated pollutant loads for the future conditions were compared to the 1976 calculated loads, and incremental increases or decreases were noted. Comparison of the change with the 1976 base condition loads for each pollutant constituent allowed us to prepare a subjective evaluation describing the effect of land-use change on pollutant loads. We used terms such as extreme increase, significant increase, moderate decrease, slight or no change, etc.

General resource management planning was mainly done with the RIA Program, an adaptation of a series of short computer programs developed by the Harvard Laboratory for Computer Graphics and Spatial Analysis. The RIA Program searches a grid cell data bank for selected environmental and other related information in order to perform specific environmental analyses. Four major types of analyses, as well as computer-printed graphic displays and tabulations, are possible with the RIA Program:

1. The Distance Determination Package calculates the linear distance of each grid cell from the other grid cells for any desired data category or categories.

2. The Locational Attractiveness Package employs an overlaying technique originally developed by Ian McHarg (1969) to identify those areas whose combination of locational characteristics makes them attractive for a particular activity. An "attractiveness index" value is computed for each grid cell based on the assignment of relative suitability to data variables describing various physical characteristics of the watershed.

3. The Coincident Tabulation Package inventories information within the data bank. It tells the researcher when items having a certain pair of characteristics also fall into a third category. For the Rowlett Creek XFPI Study this package was used to monitor changes in acreage of development options within all individual city boundaries.

4. The Impact Assessment Package locates areas likely to be particularly affected by a certain variable, with the interaction between two vari-

ables described in such relative terms as null impact, slight impact, moderate impact, severe impact, and extreme impact. This analysis does not produce an absolute quantitative representation of impact, but only a relative representation of potential impacts. The results can then be combined with the Locational Attractiveness Package and the Mapping Package to display areas that maximize attractiveness and minimize impact potential for a given activity.

SIGNIFICANT FINDINGS

The results of the Rowlett Creek XFPI Study will be presented in a multi-volume report scheduled for printing in late 1978. The following paragraphs and tables describe some of the more significant findings and results of the study. The information is considered preliminary at this time, as verification of study results is still under way.

Hydrologic-hydraulic findings

The effect of future development on flood discharges and flood stages depends upon many factors, including the size, shape, and soil conditions of the watershed, and the size, shape, slope, and vegetative cover of the stream channel and overbanks. The hydrologic analyses on the Rowlett Creek watershed showed that urbanization would not consistently affect peak discharges on the various streams. In general, peak discharges would increase as significant development was projected to occur above a discharge determination point. In some cases peak discharges might actually decrease with increased urbanization. This can occur when new development accelerates the runoff in the lower portion of a watershed in advance of the flood crest from upstream. The most important factors that influence flood discharge peaks appear to be the size and type of development and where it is sited in the watershed.

Discharge frequency curves for 1976 and the alternative future land conditions tend to converge for the rarer events and diverge for the more frequent occurrences. This implies that urbanization, which produces more impervious area, increases flood peaks more significantly for smaller (more frequent) floods.

The general trend in the Rowlett Creek watershed toward significant increases in flood peaks resulting from urbanization is more pronounced for smaller drainage areas. Although the percentages vary greatly from watershed to watershed, the study showed 7% to 14% increases in the largest areas (5 to 137 square miles) and a maximum of 30% increase in a small area (1.87 square miles). These trends imply that significant hydrologic changes take place as urban development occurs, especially in smaller drainage areas. The more frequent storms, such as 2-year or 10-year frequency floods, are most affected.

The increases in flood flows naturally tend to increase flood depths along the streams and to inundate wider areas. In some streams of the study area, the 10-year frequency flood stages for future conditions were equivalent to 100-year frequency flood stages under existing conditions. Maximum increase in depth for the 10-year flood was found to be 1.3 feet, although most 100-year flood stage increases were 0.5 foot or less. As we might expect considering the hydrology findings, the more significant increases in flood depth will occur in the smaller drainage areas. Table 1 shows some of the computed discharges and corresponding stages for several locations in the Rowlett Creek watershed.

Findings on economics of flood damage

Our flood damage calculations were prepared on a stream-reach (damage-reach) basis, considering each of the five basin-wide land-use conditions defined by the areal extent and spatial location of 22 distinct land-use categories. To simplify presentation, however, the flood damages calculated for each of 88 damage reaches were grouped by planning-area boundaries (8) and watershed boundaries (15), and the 22 land-use categories were reduced to 10 categories.

Significant increases in urbanization, with corresponding decreases in rural acreage, are reflected in the flood-damage calculations. The study area was about 6% urban in 1964, progressing to about 20% urban in 1976 (our base year). Projected urbanization would result in a study area that is 35% urban under Alternative A conditions, 70% under Alternative B, and 94% under Alternative C.

Table 2 summarizes the flood damages that could be expected to occur in the entire study area for the various land-use patterns, with and without certain floodplain regulation policies. It includes single-event damages for 10-year (10%) and 100-year (1%) frequency floods, as well as average annual damages for these floods. The three floodplain management policies that were considered for each alternative future are described below.

Policy 1: No floodplain regulations. Future development may be located anywhere, including within the 1976 100-year floodplain.

Policy 2: Minimum floodplain regulations. Future developments must have finished floor heights at the 1976 100-year flood elevation. Limited fill or flood proofing is allowed (protecting to the existing 100-year elevation).

Policy 3: Stringent flood plain regulations. A *floodway* is defined as the part of the floodplain that suffers a one-foot maximum rise in the 100-year flood level when a hypothetical wall paralleling the stream channel intrudes onto the floodplain. Development is allowed in the floodway fringe (inside the floodplain but outside the floodway) if it is built with the ground floor one foot above the 1976 100-year flood elevation.

The potential for significant flood damages in the study area increased

TABLE 1

ROWLETT CREEK XFPI
HYDROLOGIC FINDINGS

Stream	Drainage Area (sq mi)	1976 Conditions		Ultimate Development Conditions	
		Flow (cfs)	Elevation (ft-msl)	Flow (cfs)	Elevation (ft-msl)
10-YEAR PEAK FLOW AND ELEVATION					
Rowlett Creek	137	29,000	440.2	33,600	440.9
Spring Creek	34	15,600	505.4	16,800	505.9
Bowman Branch	1.5	2,700	591.4	3,350	592.0
100-YEAR PEAK FLOW AND ELEVATION					
Rowlett Creek	137	60,000	444.7	64,000	445.2
Spring Creek	34	25,700	508.4	26,100	508.5
Bowman Branch	1.5	4,100	592.8	5,150	593.9

TABLE 2

SUMMARY OF FLOOD DAMAGES FOR THE ROWLETT CREEK STUDY AREA

	1976	Alternative A	Alternative B	Alternative C	1964
SINGLE EVENT DAMAGES ($1,000)					
• 10-Year Event					
Policy 1: No Floodplain Regulations	$ 566	$18,500	$77,700	$106,000	$242
Policy 2: Minimum Floodplain Regulations	—	690	838	883	—
Policy 3: Stringent Floodplain Regulations	—	693	736	736	—
• 100-Year Event					
Policy 1: No Floodplain Regulations	1,910	40,100	163,000	209,000	590
Policy 2: Minimum Floodplain Regulations	—	2,700	5,700	11,300	—
Policy 3: Stringent Floodplain Regulations	—	4,270	5,640	7,920	—
AVERAGE ANNUAL DAMAGES ($1,000)					
Policy 1: No Floodplain Regulations	203	6,920	31,400	43,400	78
Policy 2: Minimum Floodplain Regulations	—	404	742	964	—
Policy 3: Stringent Floodplain Regulations	—	315	350	385	—

proportionately with the change from rural to urban land uses. The 100-year frequency (1%) flood, should it occur under 1976 conditions, would cause about $1,910,000 in damage as compared to $590,000 for 1964 conditions, a 220% increase (compared to 330% urbanization increase). Average annual damages increased from $78,000 to $203,000 per year from 1964 to 1976.

The consequences of allowing unrestricted floodplain development are illustrated by the average annual damages (AAD) to be expected in the study area for future conditions without regulations. For example, the Alternative A (1990) average annual damages of $6,920,000 would be a thirty-four-fold increase compared to damage expected under regulated conditions, and Alternative B ($31,400,000 AAD) would be about a one-hundred-fifty-fold increase from regulated conditions. Comparable figures can be seen in table 2 for the 10-year and 100-year single event flood damages.

Environmental findings

During the preparation of the environmental inventory for the Rowlett Creek Study area and the subsequent analyses on the implications of growth for the environmental habitats and their attendant biota, the following observations were made:

1. The Rowlett Creek Study area is not ecologically unique.

2. Several species of flora and fauna that are rare, threatened or endangered, or of special concern can possibly occur within the Rowlett Creek Study area (see table 3).

TABLE 3

SPECIES OF CONCERN

COMMON NAME	HABITAT CATEGORY	AREA OF CONCERN
Big Bluestem	Residential, Urban, Parks and Open Space, and Grassland	TOES[1]
Texas Bluegrass	Residential, Urban, Parks and Open Space, and Grassland	TOES
Eastern Gammagrass	Grassland, Forest Land, and Fence Rows	TOES
Peregrine Falcon	Grassland	USFWS[2]
Osprey	Wetlands	USFWS

1. Texas Organization for Endangered Species, 1975.

2. U.S. Department of Interior, Fish and Wildlife Service, 1975.

3. One small area of virgin prairie, about 30 acres, exists within the Rowlett Creek Study area. This area is known as Coit Meadow.

4. Pollutant loadings for BOD_5, nitrogen, and phosphorus can be expected to increase in an almost direct relationship to urbanization of the study area. For example, a doubling of urban acreage would result in an approximate doubling of BOD_5, nitrogen, and phosphorus loads.

5. The increase in nutrient (nitrogen and phosphorus) loadings as urbanization progresses can be expected to compound the existing eutrophication problems of Lake Ray Hubbard (the terminus of Rowlett Creek).

CONCLUSIONS

The basic methodology used for the Rowlett Creek Expanded Flood Plain Information Study was definitely applicable to this type of water resources planning. The grid cell data management concept provides flexibility, as well as expedient and consistent analysis of multiple-alternative watershed conditions. But the collection, encoding, and processing of massive quantities of physical data necessary for the creation of the data bank was a costly and time-consuming task, diminishing the suitability of the concept for universal application. It is hoped that advances being made in automatic encoding procedures will reduce time and costs, making this approach more attractive for a wider spectrum of studies.

The results of the study should positively affect planning at the local level in the Rowlett Creek watershed. The data presented in the forthcoming report provide more comprehensive floodplain information, integrating hydrologic, economic, and environmental implications of urban growth. The study validates and reinforces the need for floodplain management regulations to reduce potential damages.

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